Survey on Opportunistic Routing in Multihop Wireless Networks

A. Triviño-Cabrera, S. Cañadas-Hurtado

Dpto.TecnologíaElectrónica, E.T.S.I. Telecomunicación, University of Málaga, Spain
atc@uma.es

Abstract: Opportunistic routing is based on the use of broadcast transmissions to expand the potential forwarders that can assist in the retransmission of the data packets. The receptors need to be coordinated in order to avoid duplicated transmissions. This is usually achieved by ordering the forwarding nodes according to some criteria. The proposed opportunistic routing protocols differ in the criterion to order the receptors and the way the receptors coordinate. This paper presents a survey of the most significant opportunistic routing protocols for multihop wireless networks.

Keywords: Opportunistic, routing, protocol, wireless network, coding-aware, geographical, hop-count-based.

1. Introduction

Multihop wireless networks refer to wireless networks where the nodes collaborate in order to enable the communication between distant (no-connected) nodes. Multihop wireless networks comprise a wide variety of scenarios where they can be used. Depending on the capabilities and characteristics of the nodes that form the network, multihop wireless networks can be classified in wireless mesh networks, wireless sensor networks and Mobile Ad hoc NETworks (MANET).

In order to support the multihop communications, specific routings protocols are necessary. Routing in multihop ad hoc networks is supported by the collaboration of intermediate nodes that retransmit the messages from the source to the final destination. Thus, packets are said to hop from node to node. The sequence of nodes that a packet traverses from the source to the destination constitutes a path. In real scenarios, there exist multiple paths that may communicate any two nodes. Routing protocols are in charge of discovering and selecting the path to use for the communication. Depending on when the paths are discovered, we can differentiate two routing paradigms: traditional and opportunistic routing. Traditional routing is based on the discovery of a path previously to the transmission of the packet. This discovery could be accomplished on demand (reactive protocols), periodically (proactive protocols) or selecting one of the former strategies depending on the distance to the final destination (hybrid protocols). In this routing scheme, we find well known protocols such as AODV (Ad hoc On Demand Distance Vector) [1] , DYMO (Dynamic MANET On Demand) [2] or OLSR (Optimised Link State Routing) [3]. The discovery of the paths in traditional routing protocols is supported by specific routing packets which are introduced in the network. In order to detect the best paths for the communications, these packets store the costs of the links that they traverse. Examples of costs are the number of hops in the path, the probability of packet loss, the estimated delay along the path, etc. This cost information is then used by the nodes to determine the path to use. After this decision phase, the selected paths are stored in the nodes' routing caches until the routing protocol considers that they have become stale. This could happen when an error in the packet transmission is detected or when the route has not been employed for a certain time (usually greater than 10 seconds). As can be observed, this strategy assumes that the links costs computed in the route discovery remains stable while the routes are kept in the nodes caches. Due to the dynamic nature of wireless links, this condition does not hold.

An additional problem of traditional routing schemes relies on the supposition that the network is connected, that is, there is an end-to-end path between any source and any destination. However, node mobility, node sparseness or the propagation variations could lead to situations where the network is disconnected. Under these circumstances, traditional routing protocols are unable to operate. However, the communication could be effective if intermediate nodes store the message to send and they get connected to the final destination in a near future.

The above mentioned problems are overcome by opportunistic routing protocols. Instead of selecting a node to act as the next hop a-priori, the relay node is determined when the data packet is being transmitted. Moreover, this decision is carried out for each data packet so the instantaneous radio conditions are taken into account in order to select the best relaying node. To proceed, opportunistic routing protocols take advantage from broadcast transmission that allows multiple nodes to receive the same data packet with just one transmission. Then, the receptors of the packet coordinate to elect one of them as the next transmitter. It is important to remark that this election is supported by the current propagation characteristics so it differs from one packet to another. Thus, opportunistic routing leads to a load balancing while it increases the robustness of the multihop wireless network as multiple receptors are potential relays. This paper describes the main proposals about opportunistic routing protocols for wireless mesh networks and MANETs.

The rest of the chapter is structured as follows. In Section 2, we detail how a basic opportunistic routing protocol works. In Section 3, we describe the metrics used to quantify the convenience of a node to forward a packet. According to the type of metric, we have made a classification of the opportunistic routing protocols as shown in Section 4. Section 5 describes the main research guidelines concerning this subject. Finally, Section 6 presents the main conclusions of this review.

2. Basic Operation of Opportunistic Routing in Multihop wireless networks

Opportunistic routing is based on the broadcast transmissions of the data packets. This type of transmission is used in order to increase the probability that at least one potential relaying node receive s the packet. Next figure illustrates the advantage of broadcast transmissions. The source (*S*) needs to send packets to the destination (*D*). It knows that its neighbors *N1*, N2 and *N3* provide different paths to the destination (*path1*, *path2* and *path3*). It has also estimated the loss probability in each link (LLP) to its neighbor. Specifically, the link to *N1* has a loss probability of 0.2 while to *N2* and to *N3* the loss probability is 0.3 and 0.4 respectively.

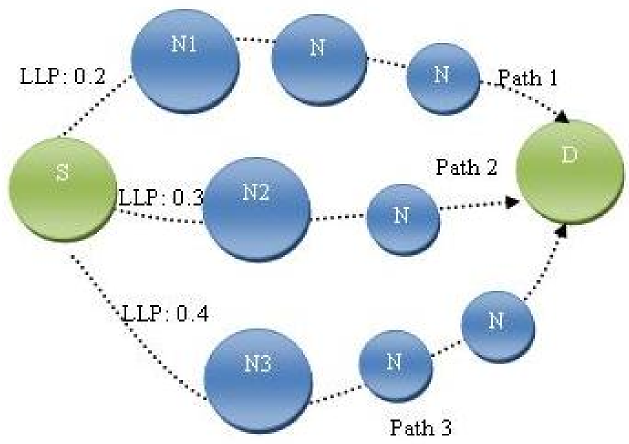

Figure 1. Connections in a wireless network to illustrate the benefits of opportunistic routing.

Using traditional routing, the Source *S* should select one of these potential forwarders as the next hop. Then, it will send the packet to this neighbor by a unicast transmission. Taking into account the loss probability, the source will select *N1* as the next hop and the probability that the packet is not retransm itted is 0.2. Alternatively, opportunistic routing will em it the packet in broadcast so the three neighbors (and some others too) will be able to receive it and to retransmit it. The probability that the packet will not be retransmitted is equivalent to the probability that no neighbors will receive the packet. This probability is 0.2•0.3•0.4, that is, 0.024. As we can see, the loss probability obtained with the opportunistic strategy is much lower than the resulting from the traditional routing.

In order to better understand how opportunistic routing works, we will p ay attention to the sequential phases that form part of an opportunistic routing protocol. These phases are:

• Candidate Selection: The protocol in the Layer-Three in the IP stack selects a set of nodes that allow the transmission of the packet from the source to the destination. This set of candidate relays is known as the forwarding candidates, the candidate forwarder set or the relay set. The nodes in the list may be ordered according to som e criteria in the second phase. The source i nforms about its relay set including the IDs of the candidates belonging to the forwarding list in the packet header. In order to reduce the space required to store all the addresses of the relay set in the packet headers, a Bloom filter is suggested in [4].

• Candidate Priority Assignment: When the source informs about the forwarding candidates, it orders them according to their convenience to act as relaying nodes. The appropriateness of a node i s based on som e metrics. For instance, the metrics could be derived at the MAC layer such as the loss probability. Nodes should periodically measure these parameters.

The relay set plays an important role in opportunistic routing protocols. The candidate selection and its order are usually performed periodically so that the two first phases are not always executed in the emission of every data packet.

• Data transmission. The original opportunistic routing protocols are supported by the transmission of broadcast packets so that they can be received by multiple neighboring nodes. However, there are som e opportunistic routing protocols [5] where the data packets are unicast. In particular, the best forwarding node is specified in the next hop field of the packet. The other candidates receive the packet by eavesdropping.

• Receiver coordination: Among the forwarding candidates that receive the data packet, just one of them should be the relaying node for the current packet. The elected node will be also responsible for confirming the data reception at the MAC layer. Th e election is carried out by incorporating a distributed procedure in the nodes. The goal of the procedure is that the selected node should be the highest-priority relay that has successfully received the packet. In this sense, some proposals opt for modifying the MAC layer. For instance, [6] includes a list of four fields in the RTS (Ready to Send) messages. The list represents the forwarding set. The candidates reply with one CTS (Clear to Send) message sequentially. Then, the source decides about which node is going to act as the forwarding node and it sends the data to the elected node.

Although this sequence is conventionally followed, there exist alternative proposals that do not implement these phases. For instance, [7] proposes that each node decides about acting as a candidate node depending on its current location and the coordinates of the final destination. Furthermore, the prioritization is performed by the nodes without the supervision of the source.

Analyzing the basic procedure of an opportunistic routing protocol, we can conclude that its main advantage consists of reducing the loss probability. Moreover, the protocol is able to adapt itself to very dynamic topologies since there exists a high probability that one node in the relay set will be capable of assisting in the retransmission between two topology updates. Howeverthese advantagescome at a cost . The paradigm relies o n the fact th at the potential forwarders should coordinate in order to avoid multiple retransmissions. The coordination basically consists of orderi ng them according to certain metrics. This process incurs in an extra delay while the potential forwarders decide about which one is going to be the next hop.

Furthermore, the acquisition of the metrics to assign the priority in the relay set may provoke an additional overhead which may not compensate the performance improvements. In the same way, the announcement of the relay set (by means of specific messages or included in the data messages) aggravates the overhead.

Taking into account these features, opportunistic routing is specially intended for loss-sensitive applications whereas it should be avoided in those scenarios where the delay needs to be optimized.

3. Metrics used in Opportunistic Routing Protocols

The construction and ordering of the relay set highly impact on the network performance. The priority assignment of the nodes belonging to the relay set is performed according to their goodness to act as the next forwarding node. In this sense, most of the nodes in the relay set are at the same length (measured as the number of hops) to the destination. Thus, the number of hops may be employed to quantify the goodness of the nodes. In contrast, alternative metrics are used for this purpose. The metrics mainly depend on the specific implementation of the routing protocol. In this sense, the metrics can be classified as:

- Anycast Link Cost. In this case, the metric to order the candidates is based on the link properties (e.g the delivery rate on the link) or the neighbor characteristics (such as position). They are said to select the forwarding set hop-by-hop.
- Remaining Path Cost. They are also named end-to-end metrics as the properties of the remaining path (the nodes or the links in the path to the destination) constitute the metric. A simple end-to-end metric is the number of hops of the path.

Although the use of the remaining path costs could lead to optimal solutions, the acquisition of the metrics for its computation could lead to a significant overhead. Furthermore, the remaining path costs are unable to cope with intermittently connected networks.

An alternative classification focuses on the parameter that the metric aims at characterizing. Concerning the delivery rate, the most outstanding metrics are:

– ETX (Expected transmission count). It estimates the number of tries needed to successfully transmit a frame on a link. Being *s* the sender of the link and *d* the destination, the ETX is defined as:

$$ETX(s,d) = \frac{1}{d_f \cdot d_r} \qquad (1)$$

where d_f is the delivery rate on the link from the sender to the destination and d_r is the delivery rate in the other sense. The definition of this metric is extended to a path being d_f and d_r the forward and the reverse delivery rate on the complete path respectively. This metric is intended for unicast transmissions and does not consider the range of paths towards which the message could be in fact transmitted.

– EAX (Expected any path transmissions). Defined in [8], this metric captures the expected number of transmissions following an opportunistic forwarding scheme. In this sense, the probability of having a number or transmission depends on the candidate nodes that retransmit the packet and their corresponding priority. Thus, the EAX from a source *s* to a destination *d* is defined as:

$$EAX(s,d) = \frac{1 + \sum_{i=1}^{N} EAX(C_i^{s,d}, d) p_i \prod_{j=1}^{i-1}(1-p_j)}{1 - \prod_{i=1}^{N}(1-p_i)} \qquad (2)$$

where the source s has N candidates to communicate with the destination. The candidates are ordered so $C_i^{s,d}$ has a higher priority than $C_j^{s,d}$ if $i < j$. The probability delivery from s to $C_i^{s,d}$ is p_i. When the source and the destination are directly connected, $EAX(s,d) = ETX(s,d)$.

Concerning the geographical-based metrics, the most used metrics are:

– Packet Advancement. It measures how much closer to the final destination *d* the packet is when received by a candidate *c*. It is compared to the distance from the source s to the destination *d*. Formally, the metric is defined as:

$$D_{sc} = Dist(s,d) - Dist(c,d) \qquad (3)$$

where $Dist(i,j)$ represents the Euclidean distance between node i and node j .

– Bit-meter advancement per second. This metric takes into account the packet advancements for the different transmission rates that are available in the network. It is specially indicated when the network is supported with a wide variety of radio technologies. Its definition can be found in [9].

4. Classification of the Opportunistic Routing Protocols

One of the main features of the opportunistic routing protocols is how to determine the forwarding set and how to assign the priority to the nodes in the set. In order to quantify the convenience of a node to belong to this set, that is, to determine its priority, a metric is used. Depending on the kind of metric, we have classified the opportunistic routing protocols in the following groups:

- Geographical information based routing Protocols. Forwarding candidates are selected according to their location information.
- Delivery-Rate Based routing Protocols. The forwarding nodes are chosen basing on the loss probabilities of the link from the source to the destination.
- Hop-Count Based routing Protocols. The distance

(measured as the number of hops) of the paths from the neighbors to the distance is used to determine its convenience to act as the next hop.

- Code-Aware routing protocols. In these protocols, the packets are coded when emitted.
- Generic routing Protocols. Their proposals do not restrict the routing protocols to work with any specific kind of metrics.

The following Subsections describe the main proposals in each group.

Geographical information based Opportunistic Routing

Geographical information based routing protocols are supported by the assumption that each node has some knowledge about its position and the others nodes positions. One-hop beacon messages including the source's coordinates are usually exchanged in order to maintain an updated location based table. In order to access to further nodes, a location services is necessary. The location service provides any node's coordinates, even when the node is not in the neighborhood.

A preliminary version of opportunistic geographic routing protocols is in the contention-based geographic forwarding schemes [10]. These proposals are also known as state-free schemes because nodes do not exchange link-state messages. Alternatively, the sender emits a control packet when it needs to send a data message. The receiving nodes independently decide about their suitability of retransmitting the data message according to their distance to the destination. Particularly, the potential relay nodes are within the forwarding area, that is, they are closer to the destination than the source. Then, the candidate contends with other neighbors to decide about which one is going to be the relaying node. Once decided, the source sends the data packet to the elected next-hop. As in opportunistic routing protocols, there are a set of nodes competing to be the next relay and they coordinate to select just one retransmitter. The main difference is that this process is carried out when a control packet is generated.

The way the candidates are selected from this geographical information leads to different opportunistic routing protocols. In [11], the candidates are selected according to the packet advancement. In particular, those with the higher packet advancement are preferred. However, in order to prevent routes from diverging, the packet advancement of a potential candidate is compared to the highest packet advancement of all the source's neighbors. The difference between these two quantities cannot exceed a predefined threshold in order to include the potential candidate in the forwarding list. In this way, the algorithm also ensures that the nodes in the forwarding list can hear other node in the list transmitting. This condition avoids duplicated retransmissions. In a similar way, the proposal in [5] orders the candidates according to their distance to the destination, i.e. the nodes that are closer to the destination have a higher priority. Up to five neighbors may be included in the data headers. As we can see, in these proposals the source is responsible for ordering the candidates in the forwarding list.

On the contrary, in GeRaF (Geographic Random Forwarding) [7], the candidates are not selected by the source. Instead, the nodes decide about acting as retransmitters or not when they receive the data packet. The protocol is supported by the geographical information contained in these packets. Specifically, the source generates the data packet containing the source location and the destination coordinates. Then, the receiving node computes their distance to the destination. Just the nodes that are closer to the destination than the source are potential retransmitters. A mechanism is necessary to determine which one is going to act as the relaying node. Towards this goal, the coverage area of the source is divided into annulus. Those potential retransmitters staying in a closer annulus confirm the reception of the packet later than those remaining in an outer annulus (because they are closer to the final destination). The procedure is repeated in all the relaying nodes until the packet reaches the final destination.

The scheme presented in [9] deals with multiratemultihop ad hoc networks. Explicitly, it focuses on the appropriateness of the neighboring nodes to act as the forwarding nodes for the different transmission rates. In order to quantify this appropriateness, a new metric is proposed. The metric, named 'bit meter advancement per second', combines the packet advancement for every transmission rate.

In the previous proposals, the data packets are transmitted as broadcast in order to enable multiple nodes to receive the packets. Alternatively, [5] presents an opportunistic scheme where data packets are unicast. In particular, the best candidate is set as the next hop of the packets but neighboring nodes receive the packet by eavesdropping. A candidate in the forwarding list is ordered according to its distance to the destination and the number of its neighbors that could make a positive progress to the destination. The algorithm also includes a technique to cope with obstacles. In particular, the center of the obstacle is used as a virtual destination. Thus, the packets can progress to the real destination even when obstacles are present.

As we can see, the presented geographic schemes assume that the closer the node is to the destination, greater the advancement is. However, in vehicular scenarios this condition does not hold because nodes move in restricted areas defined by the road topology. In this context, [4] describes an algorithm to define the forwarding area according to the road topology. The nodes in the forwarding area are considered the candidates.

Hop-Count -Based Protocols

In these algorithms, the number of hops that compose the path to the destination is used to construct the forwarding set. It is considered convenient when the topology of the network varies frequently. The OPRAH protocol [12l] is supported by the modification of the AODV. In particular, AODV is customized to discover multiple routes to one destination. The routes are valid when the number of hops that they have do not exceed the length of the (so far) optimum path in a configurable parameter. The MAC is not modified so the packets are sent in a broadcast mode and the candidates do not confirm its reception. The way the candidates are assigned the priority is not specified. Moreover, there is not any technique to avoid the emission of multiple data packets. In this sense, the authors recommend that the control should be performed at the application layer.

In [6], AOMDV (Ad Hoc Multipath Distance Vector) is used to discover multiple routes from the source to the destination on-demand. Then, the candidates are assigned a priority according to their path length (measured as the number of hops). The coordination of the candidates is guaranteed by altering the MAC layer. In particular, the RTS messages include the forwarding list (limited to four candidates) and all the receiving candidates respond with a CTS. Then, the source selects the current next-hop and it emits the data packet to the elected one.

Delivery Rate Based Protocols

The ExOR (Extremely Opportunistic Routing) protocol assumes that all nodes know the loss rate in every wireless link [13]. A link state routing may be employed for this purpose. The forwarding list is then ordered according to the number of hops. When there are multiple neighbors whose path to the destination possesses the same number of hops, they are ordered basing on the delivery rate. The ordered list is then included in the data packet header. When a candidate receives the packet, it must reply with an ACK frame (the Link Layer is modified to incorporate this additional functionality). The emission of the ACK is also ordered so that the node with a higher priority responds first. Additionally, the ACK includes the identification of the candidate with the highest priority that has sent a previous ACK according to the ACK sender. In this way, candidates could be aware of the reception of the packets by no neighboring nodes. However, the retransmission of the data packet is delayed as the nodes should wait for the complete sequence of slots assigned for each candidate to emit its ACK. Once this period is over, the nodes decide about retransmitting the message basing on the information learnt in the ACK frames.

Basing on the ETX metric, SOAR (Simple Opportunistic Adaptive Routing) selects the forwarding set [14]. Just the neighbors with a lower ETX to the destination are potential candidates. However, the set of candidates is reduced since the main goal of the protocol is reducing the emission of duplicated messages. With this objective, the link-state routing used to acquire the ETX information of the links also provides the default path, that is, the path with the lowest ETX. The nodes in the forwarding set are constrained to be close to the default path so that there exists a high probability that they can overhear other candidates' transmissions. In a similar way to previous proposals, the candidates start the retransmission of the packets when one internal timer is over. The timer is set according to the node position in the forwarding list.

In [8], the ExOR is modified so that the candidate nodes are selected according to the EAX metric. Firstly, the potential candidates must hold a lower ETX to the destination d than the source s. The neighbor node with the lowest ETX is included in the forwarding list with the highest probability. Then, a potential candidate j is incorporated in the list if its $EAX(j,d)$ reduces $EAX(s,d)$ by a factor of at least ψ, which is a configurable parameter. Since EAX is a remaining path cost, the quality of the paths to the destination is considered.

A novel metric is presented in [15]. The metric captures the congestion on the link so that a traffic load balancing can be performed.

On the other hand, the proposal in [16] describes an opportunistic routing protocol for multicast communications named ROMP (Reliable Opportunistic Multicast routing Protocol). The Steiner tree is constructed basing on ETX measures. Then, nodes close to the tree are considered as candidates. The preference for the nodes depends on their closeness to the tree and the delivery probability to the destination. A new metric is proposed to measure the contribution of these two parameters to the successful delivery to the complete set of destinations. Thus, ROMP is supported by a remaining path cost. The data packet contains the forwarding list. The receiving nodes in the list retransmit the packet according to the order in which its identification is in the list. The protocol assumes that other nodes can listen to other candidates' retransmissions to guarantee their coordination.

Coding-Aware Routing Protocols

Coding data packets can reduce the number of transmission in a network as M packets can be coded in N packets where $M > N$. Furthermore, coding simplifies the scheduling in wireless networks. The data packets in a session are grouped into segments, batches or generations. The destination confirms every segment independently.

Applied to opportunistic routing, coding impacts on the retransmitted packets. In fact, the intermediate nodes do not retransmit an exact copy of the received data packet but it usually generates a new coded packet from all the previously received packets belonging to the batch. This new packet is then broadcast as in conventional opportunistic routing.

MORE (MAC Independent Opportunistic and Encoding Protocol) [17] is a coding-aware routing protocol. In MORE the data packets are always coded for their emission. The source emits a linear combination of the packets in the same batch. In the packet header, the source also includes the forwarding list. The candidates are the nodes with a lowest ETX to the destination then the source and they are given the priority to act as the relay node according to this metric. Upon reception, the candidate checks if the packet is innovative, that is, if it contains new information not included in the previous data packets from the same batch. If so, the candidate retransmits a new coded packet generated from the received data packets. The reception of the data packets at the destination is performed at the application layer so the MAC layer does not need to be altered. However, the paper presents two significant drawbacks. Firstly, no coordination among the candidates is described in the proposal. Additionally, the source transm its coded packets of the same batch until the destination confirms that it could decode the packets. By this restriction, only the packets related to one batch are on the fly even when the network resources are not fully occupied. In order to overcome this limitation, [18] opts for transmitting coded packets from different segments. A window-sliding mechanism is suggested to manage the simultaneous transmissions of different batches. The transmission rate can be also adjusted through CCAK [19]. In this scheme, intermediate nodes acknowledge coded traffic to their upstream neighbors.

CORE [20] is also a coding-aware routing protocol but the priority of the candidates in the forwarding set is dynamically established according to the coding opportunities. A node X is said to have more coding opportunities than node Y when it holds more packets to be coded. In order to be a candidate, the node must be a neighboring node of the source and it must be (geographically) closer to the destination than the source.

Generic Routing Protocols

In this category, we include the opportunistic routing protocols that deal with a generic metric, that is, they can be use independently of the type of metric.

ROMER (resilient and opportunistic routing solution for mesh networks) [21] is an opportunistic routing protocol for mesh networks based on credits. By credits, the protocol specifies the cost incurred in the transmission of a packet. The paper in [21] does not specify the kind of metric for which the protocol is intended but it suggests that it could be related to energy consumption. Given a data packet, the application attaches to it a credit which is the minimum cost for transmitting the packet from the source to the gateway (i.e. the most common traffic in a wireless mesh network) plus an extra cost to allow the discovery of multiple routes. From the source to the destination, only the paths not exceeding the credit can be discovered. However, the algorithm to construct the mesh from the source to the destination recommends that the consumption of the credit should be higher in the areas closer to the source. Once the mesh is constructed, the transmission of the data is probabilistic. In this way, the source always sends the data packet to the candidate node with the highest link rate. Alternatively, other candidates receive the packet basing on a probability related to their link quality. As we can see, the data packet is simultaneously sent through multiple paths.

Table 1 summarizes the main characteristics of the described routing protocols.

5. Future research directions

The main issue in opportunistic routing relies on the construction of the relay set. Towards this goal, the most recent works about geographic routing focus on adapting to the physical conditions of the environment. In this sense, the presence of obstacles should be taken into account. When dealing with mobile networks such as VANET, opportunistic routing is leading to including the mobility restrictions such as the road topology into the phases of constructing the forwarding relay and given the priority to the components of this set.

On the other hand, coding packets to transmit them in an opportunistic way has improved the network performance and, therefore, it is one of the major design guidelines in the current development of opportunistic routing protocols.

6. Conclusions

Opportunistic routing protocols present a promising scheme to improve the wireless network performance by exploiting the broadcast nature of the medium. The main concern of theses protocols relies on which neighboring nodes should forward the data packets and how to coordinate them to avoid duplicated retransmissions. The way to select the relays is supported by metrics. This paper has reviewed the main proposals for multihop ad hoc networks and we have classified them according to the kind of metric used. We can see that the geographic and link-quality based routing protocols have been extended by coding opportunistic routing protocols.

Acknowledgment

This work has been supported by the FEDER - MCINN Project No. TEC2009-13763-C02-01.

References

[1] C. Perkins, E. Belding-Royer, S. Das, "Ad hoc On Demand Distance Vector (AODV) Routing", IETF RFC 3561, July 2003.

[2] I. Chakeres, C. Perkins, "Dynamic MANET On-demand (DYMO) Routing", IETF internet draft (work in progress), July 2010.

[3] T. Clausen, P. Jacquet, "Optimised Link State Routing (OLSR)", IETF RFC 3626, October 2003.

[4] K. C. Lee, U. Lee, M. Gerla, "Geo-opportunistic routing for vehicular networks", IEEE Communications Magazine, May. 2010

[5] S. Yang, C. K. Yeo, B. S. Lee, "Robust Geographic Routing with VirtualDestination based Void Handling for MANETs", in the Proc. of the IEEE 71st Vehicular Technology Conference (VTC 2010-Spring), May 2010.

[6] S. Jain, S. Das, "Exploiting Path Diversity in the Link Layer in Wireless Ad Hoc Networks", in the Proc. of the 6th IEEE WoWMoM Symposium, 2005.

[7] M. Zorzi, R. R. Rao, "Geographic random forwarding (GeRaF) for ad hoc and sensor networks: energy and latency performance", IEEE Transactions on Mobile Computing, vol. 2, Issue 4, October 2003.

[8] Z. Zhong, J. Wang, G-H. Lu, S. Nelakuditi, "On Selection of Candidates for Opportunistic Any-Path Forwarding", ACM SIGMOBILE Mobile Computing and Communications Review, Vol. 10 Issue 4, October 2006.

[9] K. Zeng; Z. Yang; W. Lou, "Location-Aided Opportunistic Forwarding in Multirate and Multihop Wireless Networks", IEEE Transactions on Vehicular Technology, Vol. 58, Issue 6, July 2009.

[10] D. Chen, J. Deng, P.K.Varshney,"Selection of a Forwarding Area for Contention-Based Geographic Forwarding in Wireless Multi-Hop Networks", IEEE Transactions on Vehicular Technology, Vol. 56, Issue 5, September 2007.

[11] X. Yang, J. Yin, S. Yuan, "Location-Aided Opportunistic Routing for Mobile Ad Hoc Networks", in Proc. of the 5th International Conference

onWireless Communications, Networking and Mobile Computing, 2009(WiCom '09), September 2009.

[12] C. Westphal, "Opportunistic Routing in Dynamic Ad Hoc Networks: the OPRAH protocol", in Proc. of the IEEE International Conference on Mobile Adhoc and Sensor Systems (MASS), October 2006.

[13] S. Biswas, R. Morris, "Opportunistic Routing in Multi-Hop Wireless Networks", in Proc. of the Conference SIGCOMM, 2005.

[14] E. Rozner, J. Seshadri, Y. A. Mehta, L. Qiu, "SOAR: Simple Opportunistic Adaptive Routing Protocol for Wireless Mesh Networks", IEEE Transactions on Mobile Computing, Vol. 8, nº 12, December 2009.

[15] M. Naghshvar, T. Javidi, "Opportunistic Routing with Congestion Diversity in Wireless Multi-hop Networks", in Proc. of the IEEE Conference INFOCOM, November 2010.

[16] W.Z. Yang, Z. Y. Zhang, B. Wang Bo, X. H. Wu, "A Reliable Multicast for MANETs Based on Opportunistic Routing", in Proc. of the IEEE International Conference onWireless Communications, Networking and Information Security (WCNIS), June 2010.

[17] S. Chachulski, M. Jennings, S.Katti, D.Katabi, "Trading Structure for Randomness in Wireless Opportunistic Routing", in Proc. of the IEEE International Conference SIGCOMM, August 2007.

[18] Y. Lin, B. Li, B. Liang, "CodeOR: Opportunistic Routing in Wireless MeshNetworks with Segmented Network Coding", in Proc. of the IEEE International Conference onNetwork Protocols, October 2008.

[19] D. Koutsonikolas, C-C. Wang, Y. C. Hu, "CCACK: Efficient Network Coding Based Opportunistic Routing Through Cumulative Coded Acknowledgments", in Proc. of the IEEE Conference INFOCOM, November 2010.

[20] Y. Yan, B. Zhang, J. Zheng, J. Ma, "CORE: a Coding-Aware OpportunisticRouting Mechanism for Wireless Mesh Networks", IEEE Wireless Communications, June 2010.

[21] Y. Yuan, H. Yang, S. H.Y. Wong, S. Lu, W.Arbaugh, "ROMER: Resilient Opportunistic Mesh Routing for Wireless Mesh Networks", in Proc. of the 1st International Conference on Wireless Mesh Networks (WiMesh), 2005.

Protocol Name	Group	Link /Path Cost	Selection of the nodes in the forwarding list	Coordination of the relay set
Contention-Based Geographic Forwarding	Geographical-information based	Link	Forwarding area	Packet Advancement
GeRaf	Geographical-information based	Link	Forwarding area	Belonging to different annuluses around the source, which represent the distance to the source.
Location-aided opportunistic forwarding	Geographical-information based	Link	Forwarding area	Bit meter advancement
Robust Geographic Routing	Geographical-information based	Link	Forwarding area	Packet Advancement and the number of neighbors
Geo-opportunistic Routing	Geographical-information based	Link	Forwarding area	Packet Advancement and the road topology
OPRAH	Hop-Count Based	Path	Number of hops to the destination	Not specified
ExOR	Delivery Rate based	Path	Number of hops to the destination	Number of hops and ETX
Opportunistic Any Path Forwarding	Delivery Rate based	Path	Lower ETX than the source	EAX
SOAR	Delivery Rate based	Path	Number of hops to the destination and distance to the default path	Number of hops and ETX
Opportunistic Routing with Congestion Diversity	Delivery Rate based	Path	Number of hops to the destination and congestion	Congestion
Reliable Opportunistic Multicast routing	Delivery Rate	Path	Lower ETX than the source	Closeness to the Steiner tree
MAC Opportunistic and Encoding Protocol	Coding-aware based	Path	Lower ETX than the source	ETX
Coding-Aware Opportunistic Routing	Coding-aware	Path	Forwarding area	Coding opportunity
ROMPER	Generic	Path	Path cost (e.g. energy consumption)	Link rate

Table I. Summary of the main features of the opportunistic routing protocols